Transportation Risk ANalysis tool for hazardous Substances (TRANS) – A user-friendly, semi-quantitative multi-mode hazmat transport route safety risk estimation methodology for Flanders

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Detailed Response to Reviewers

***Research Highlights**

- The paper develops a user-friendly and transparent way of assessing the relative risks of hazmat transportation
- It looks at risk on both a route segments and over the entire transportation route.
- Multi-criteria tables are developed for assessing the risk likelihood across a range of modes

A user-friendly semi-quantitative multi-mode Transportation Risk ANalysis tool for hazardous Substances (TRANS) – Theoretical development of hazmat transport route safety risk levels in Flanders

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Abstract
The paper develops a methodology for assessing the relative risk levels in moving hazardous materials by various transport modes. Transportation Risk ANalysis tool for hazardous Substances (TRANS) divides routes into smaller segments using multi-criteria analysis and likelihood scores of accidents in which dangerous cargoes are involved possibly causing fatalities. The consequences of accident scenarios are calculated in terms of the number of people within 1% of the lethal distance from the accident centre. This provides a user-friendly, semi-quantitative risk analysis tool. The generic method allows for comparing the risk levels of the segments of routes used in the transportation of hazardous goods.

Keywords: transportation risk analysis, transportation of dangerous substances, dangerous freights

1. Introduction

In Flanders, Belgium, there is no methodology for analyzing and prioritizing risks associated with non-fixed danger sources, such as the movement of hazardous materials. This is problematic in that Antwerp has the second largest chemical cluster in the world, and that other large chemical clusters are located nearby in the Rotterdam port area and in the Rhein-Ruhr region, with smaller clusters spread in between. Substantial hazardous goods transport takes place between these chemical clusters in a geographical area based around Flanders. Moreover, Flanders, The Netherlands and Western Germany are very densely populated providing an additional incentive to develop a transportation risk analysis methodology for the region.

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This paper develops a user-friendly semi-quantitative risk-based methodology that can relatively easy be used by policy makers in the types of situation that pertains in Flanders. The approach, called TRANS (Transportation Risk ANalysis tool for hazardous Substances), deals with determining transportation risks composed of qualitative likelihoods and quantitative consequences. It does not include or calculate frequencies, probabilities, uncertainties, etc., and thus does not build on uncertainty theory, decision science, and other quantitative-based theories using probabilities.

2. Background

To develop TRANS, the Flemish government created a steering committee with leading civil servants from the Environment, Nature and Energy and the Mobility and Public Works Departments, the Belgian federal public services mobility and transportation, and the economics units. This committee was supplemented with of a multidisciplinary team of experts for the various transportation modes involving manufacturing and transportation representatives from commerce and industry, as well as quantitative risk assessment experts. This committee envisioned a tool applicable to road, railway, inland waterways and pipelines, and that allows intra-mode as well as inter-mode hazardous movement risk assessments.

To achieve these objectives, two features were put forward by the steering committee as guidelines for the TRANS method relating to:

- providing choices between two or more routes by evaluating their risk potential;
- providing overviews of the high-risk parts of a transportation network including the “top-10” high-risk locations.

In addition, three major problems were identified that require consideration when developing a risk analysis in this context; namely the availability and reliability of some data on the transportation of dangerous goods is often poor; the system would have to be understandable for both trained professionals as well as political decision makers (user-friendliness of the tool is thus a very important feature); and planned improvements should be visible in the results of the assessment.

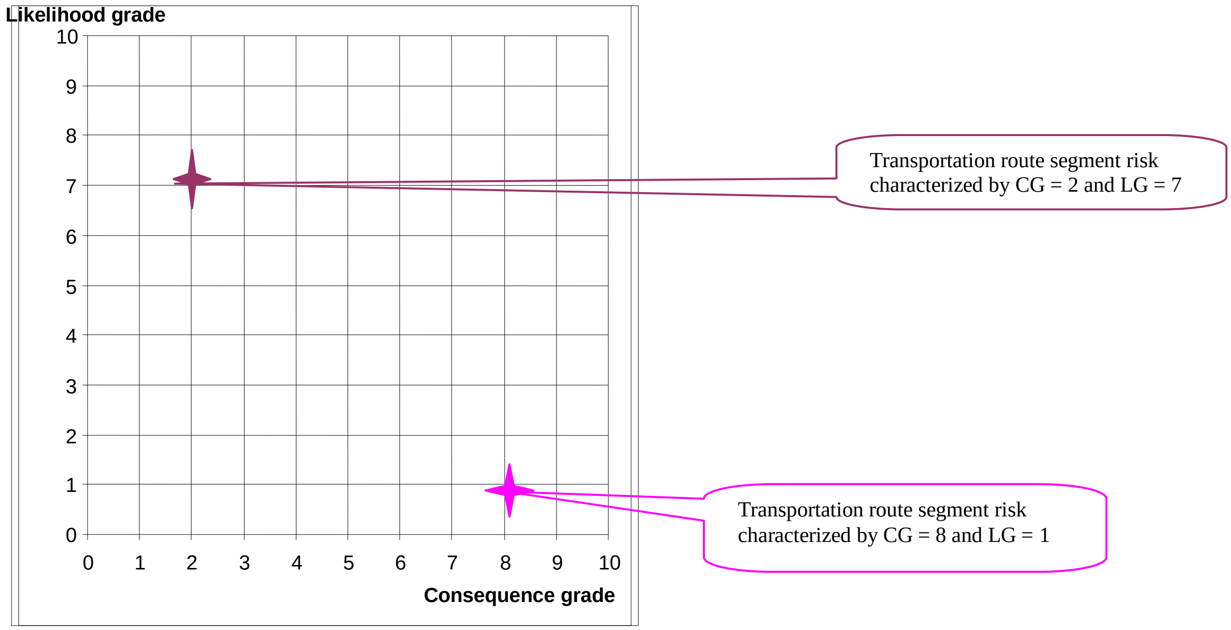
3. The TRANS methodology

Preliminaries

Given complexity and data limitations, a phased approach is used in the TRANS methodology. Initially, transportation routes are divided into a number of ’route segments’ using a purpose built methodology. Second, for each route segment, the likelihood and the possible outcome of transportation risks are determined. The likelihood and the consequences of a potential transport accident are both assessed by the TRANS user in a user-friendly way.

A diagram is employed to map a transportation risk, indicating its likelihood on the vertical axis and its potential severity on the horizontal axis. By assigning a likelihood grade (LG) as well as a consequence grade (CG), a mapping point is determined (see Figure 1). This point represents the transportation risk for each route segment. Finally, the segment scores are aggregated as a transportation route risk score.

Figure 1 Likelihood-consequence diagram for mapping transportation risks using TRANS



This approach was validated in nine brainstorming sessions held between September 2008 and March 2009 involving the steering committee.

Route segmentation

In this analysis there is a need to assess the risks of a route of a certain distance and to determine both the exposed population and the nature of the infrastructure transversed. One approach to doing this is to divide the route into segments based on differences in pre-defined characteristics so that all segments are not identical but vary according to segment-defining parameters. Relevant types of segment are by:

- *location-related parameters*: these parameters influence the possible consequences of a transportation accident involving dangerous goods;
- *infrastructure-related parameters*: these parameters influence the likelihood of a potential transportation accident involving hazardous substances.

To limit potential outcomes, and to make the method more user-friendly, the number of segment-defining parameters is restricted for each mode (Table 1).

Table 1 Segment-defining parameters

a. road transport

Location related parameters
1. Population density (expressed in terms of land-use)
1a. residential area
1b. industrial area
1c. other function
Infrastructure related parameters
2. Type of road
3. Speed limit
4. Presence of junctions
When segmenting, road sections are divided into segments with a junction and segments without a junction. A junction comprises the road situated 1000m before after the junction and in case of ground floor junctions, 100m and after the junction.
5. Road tunnels are considered as a separate route segment

b. railroads

Location related parameters
1. Population density (expressed in terms of land-use)
1a. residential area
1b. industrial area
1c. other function
Infrastructure related parameters
2. Start of a new line / junctions
3. Speed limit
4. Railway tunnels
5. Railway stations

c. inland waterways

Location related parameters
1. Population density (expressed in terms of land-use)
1a. residential area
1b. industrial area
1c. other function
Infrastructure related parameters
2. ECMT-classification (classification of inland waterways according to the maximum allowed tonnages, thus indicating maximum length and width of ships, etc.)
3. Presence of junctions, dock mouths, locks
When segmenting, waterway sections are divided into segments with a junction and those without. A junction comprises the waterway situated 500m before and after the junction.
4. Speed limit

d. pipelines

Location related parameters
1. Population density (expressed in terms of land-use)
1a. residential area
1b. industrial area
1c. agricultural area
1d. other function

Remark: In the case of pipelines, the location of the pipeline influences both the likelihood of an accident and its consequences. For instance, the presence of human activity near a pipeline raises the relevance of the factor ‘external influence’ and thus increases the likelihood of a pipeline fracture. This is why agricultural cultivation is inserted as a relevant location related parameter for segmentation purposes

Infrastructure related parameters

2. Depth of pipeline
3. Wall thickness of pipeline
4. Diameter of pipeline (a new segment starts when the nominal diameter changes)
5. Presence of crossings (evaluated 50m on both sides of the pipeline)

- 5a. roads: the presence of a road in the vicinity of a pipeline increases the likelihood of roadworks;
- 5b. other pipelines (e.g. high-pressure pipelines): the presence of another pipeline increases the likelihood of domino effects;
- 5c. railroads: the presence of railroads increases the likelihood of vibrations;
- 5d. navigable waterways: the presence of inland waterways increases the likelihood of pipeline fractures due to e.g. anchor throwing.

6. Presence of wind turbines (if a pipeline part is present within a distance equal to the length of the turbine mast (± 400m) this part of the pipeline is considered a separate segment)

The likelihood grade

Based on expert opinions, parameters likely to play a crucial role in causing accidents are determined for the different transport modes. Multi-criteria analysis is used to define the likelihood grade in the likelihood-consequence diagram. Likelihood criteria are ranked for a specified route segment by mode. Table 2 offers a theoretical case.

Table 2 Example of a multi-criteria analysis to find route segment likelihood scores per substance category

		Route segment class:	*A*	*B*	*C*	*D*	*Route segment score*
Criterion	*WF*	*Relevance of class:*	*1*	*2*	*3*	*5*	
Criterion *x*	2			4			4
Criterion *y*	1				3		3
Criterion *z*	4				12		12
Score for route segment *X*							19
Route segment likelihood score determination per substance category							
Score for flammable liquids						95	95
Score for flammable gases				38			38
Score for toxic liquids					57		57
Score for toxic gases			19				19

The criteria are assessed per route segment and the degree of relevance for each criterion in a segment is defined by class. Table 3 provides an example of the likelihood criteria for each transport mode, their weighting factors and their class assignments. Experts are used to determine the criteria and the weighting factors. The selection of experts is important and should be based on solid, clear and justifiable procedures. The list of possible experts was obtained from experienced safety advisors and risk managers belonging to major organizations and familiar with hazmat transportation[1]. A set of criteria in choosing experts was used: i.e., reputation in relevant fields, familiarity with uncertainty concepts, diversity in background, balance in viewpoints, interest in the project, availability, and diversity of knowledge. Therefore, besides company specialists, experts from the Flemish Government and from academia as well as consultants were invited to participate to the brainstorming sessions. Experts' relative expertises were not taken into account, although during the brainstorming every expert had an opportunity to contribute insights, knowledge and know-how in general and especially from his/her expert domain. This way, the resulting expert-based criteria and their risk correlation with every transport mode activity can be regarded as having been validated in a qualitative way.

The higher the class in which a route segment is classified for a specific criterion, the greater the risk on that route segment. The classes *A*, *B*, *C*, and *D* are employed representing a relevance of respectively *1*, *2*, *3*, and *5*. This way, the most dangerous class (being D) will be given a larger influence on the criterion's risk contribution. The utility of the multi-criteria technique largely depends on the definitions given to clarify the classes. Furthermore, since some criteria do influence the transportation accident likelihood stronger than others, a weighting factor is assigned to every criterion. The route segment class value is multiplied by this pre-determined weighting factor (*WF*), and in this manner, a score is obtained for each criterion. A route segment score is then obtained by adding the individual scores. This score is independent of a certain dangerous substance category.

Given that without the presence of dangerous goods one is not able to assess the risk of an accident (because without dangerous goods there would be no 'hazardous freight' risk present), it is self-evident that the volume of transported hazardous materials has to play an important role in determining the likelihood of occurrence of an accident. To this end, the 'presence of dangerous goods' is subdivided into different classes ranging from A to D dependent on the overall volume of hazardous goods transported. Here a distinction needs to be made in terms of type of dangerous substance category. The lowest class is limited to the volume of dangerous good transports X_1, the second lowest value is limited to X_2, and the third lowest value is limited to X_3. All dangerous goods amounts above X_3 fall in the highest class. The set limits X_1, X_2 and X_3 depend upon the different goods' categories and on the transport mode. Next, dependent on the volume of dangerous goods the MCA-score is multiplied with a factor 1, 2, 3 or 4 (representing class A, B, C, and D for a certain substance category). In this way a route segment score is obtained for each category of hazardous goods.

Finally, the route segment score is linked to a predetermined likelihood grade. Table 4 provides an example.

[1] Although this in itself involves a high degree of self-selection and should thus be treated with care.

Table 2 Likelihood criteria, weighting factors and class-assignments by mode

a. Road

Criteria	WF	Class A	Class B	Class C	Class D
Type of road	7	Road with a central reservation and without direct entrances or crosswalks	Road with a central reservation, with junctions and entrance and exit ramps	Road with a central reservation, direct entrances or with crosswalks	Road without a central reservation, with direct entrances or with crosswalks
Speed limit (private transportation)	3	70 km/h	90 km/h	100 km/h	120 km/h
Type of junction	3	None	Overpass (entrance and exit ramps)	Controlled intersection (roundabout or traffic lights) Controlled grade crossing	Uncontrolled intersection Uncontrolled grade crossing
Traffic control	3	Control with fixed cameras	Control with mobile cameras	-	None
Intensity of freight traffic (pce = passenger car equivalent)	2	<500 pce/day	500 – 1500 pce/day	1500 – 3000 pce/day	3000 pce </day
Access to emergency services [(2)]	2	Yes	-	-	No
Intensity/Capacity (I/C) ratio per lane	2	0.5<I/C<0.7	0.3<I/C<0.5	0.7<I/C	I/C<0.3
Road quality	2	Good	Satisfactory	Poor	Bad
Local risk factors	1	None	Specific risks, frequent traffic jams	Steep slopes that meet applicable standards	High probability of fog or traffic jam Slopes that don't meet applicable standards
External risks	1	None	Natural risk factors (trees, flooding, etc) or very nearby installations (e.g. wind turbines)	Bridge/airport runway very nearby	-

b. Rail

Criteria	WF	Class A	Class B	Class C	Class D
Switches and junctions (*)	1	None	1 - 6/10 km	7 - 12/10 km	>12/10 km
Speed limit	3	60 km/h (freight)	80 km/h (freight)	100 km/h (freight) 140 km/h (passengers)	120 km/h (freight) 160 km/h (passengers)
Level crossings, crossovers	3	None	1 - 5/10 km	6 - 10/10 km	>10/10 km
Access to emergency services	2	Yes			No
Train intensity	2	0 - 10 Trains/line/hour	11 - 20 Trains/line/hour	21 - 40 Trains/line/hour	>40 Trains/line/hour

Quality of the track	2	Good quality, good maintenance	Satisfactory, poor maintenance	Outworn track, inadequate maintenance	Bad condition, inadequate maintenance
Railway signal system	5	signalling with stop function, ETCS with stop function	EBP	tout relais	Manual
Hot axle box detection	3	<25 km	50 >X >25 km	X >50 km	None (>100 km)
External risks	1	None	Natural risk factors (e.g. trees and flooding) or very nearby installations (e.g. wind turbines)	Bridge/airport runway very nearby etc.	-

c. Waterways

Criteria	**WF**	**Class A**	**Class B**	**Class C**	**Class D**
Junctions, dock mouths, locks	4	None	Lock	Dock mouth	Waterway junctions
Traffic intensity	3	<5.000 barges/year	5.000 – 15.000 barges/year	15.000 – 30.000 barges/year	>30.000 barges/year
CEMT classes	3	Class VII – VI	Class V	Class IV	Class III – II – I – 0
Access to emergency services	2	On-board intervention possible, remote intervention possible	Only remote intervention possible	-	No intervention possible within 30 minutes
Mix of barges	2	No pleasure trips, no sea shipping	Pleasure trips	Presence of sea-going vessels (>9.600 ton)	Abundant presence of sea-going vessels (Sea-Scheldt, Canal Ghent-Terneuzen)
Type of inland water	2	Docks, canals	-	Rivers	-
Speed limit	2	<8 km/h	9 – 16 km/h	17 – 21 km/h	>21 km/h, high-speed navigation tracks
Night navigation	1	Not allowed	-	-	Allowed
External risks	2	None	Natural risk factors (e.g. trees and floods) or very nearby installations (e.g. wind turbines)	Bridge/airport runway very nearby etc.	Narrowing crossover

d. Pipelines

Criteria	**WF**	**Class A**	**Class B**	**Class C**	**Class D**
Diameter of pipe	2	>22"	12" - 22"	5" - 10"	0" - 4"
Pipe wall thickness	5	>15 mm	10-15 mm	5-10 mm	<5 mm
Depth of pipes	5	>150 cm	100-150 cm	80-100 cm	<80 cm
Land use	3	Land owned by pipeline owner, pipeline strips	Rest Other	Industry, agriculture	Residential area
Pipeline in buffer zone around junctions (roads, waterways, railways, ...) or	3	No		Yes	Yes, overground pipes

within effect of an external risk factor (wind turbine,...)					
Patrouille	2	Once a week	Once a month	Once a year	None
Pipe in flooding area, water-collection area, instable area (e.g. mines)	2	No	Yes, but measures taken	Yes	
Year of construction	2	>1984	1966-1983	1954-1965	<1954
Possibility of external corrosion	1	Inline inspection with coating and cathodic protection present	Periodic monitoring of the coating and cathodic protection	Coating and cathodic protection present, but no formal inspection program these forms of protection	No protection
Possibility of internal corrosion	1	Non-corrosive substance	Corrosive substance, protection present (inhibitor, coating)	Corrosive substance, corrosion surcharge considered	Corrosive substance, no protection
Incorrect operations	1	Not possible through processes		Possible through processes	
Access to emergency services	1	Yes			No

Table 4 Relationship between route segment score and likelihood grade

Likelihood Grade	Route segment score
LG 1	$X \leq a$
LG 2	$a < x \leq b$
LG 3	$b < x \leq c$
LG 4	$c < x \leq d$
LG 5	$d < x \leq e$
LG 6	$e < x \leq f$
LG 7	$f < x \leq g$
LG 8	$g < x \leq h$
LG 9	$h < x \leq i$
LG 10	$x > i$

The values of a to i are determined for each transport mode with account being given to the combination of the segment scores and the volume of dangerous goods moved. For example, a low segment score with a low class of dangerous goods is assigned a low likelihood grade on the Y-axis. Conversely, a high segment score in combination with a large amount of dangerous goods transports involves a high likelihood grade. The combination of a low segment score with a relative high density of dangerous goods is categorized as average.

The consequence grade

For assessing the consequence grade, the effect distance for a scenario is combined with the exposure of the population to the expected consequences involved. As a measure of this, TRANS uses the 1% lethality contour – i.e. a measured used in the Seveso-industry throughout Europe. To facilitate easy use, TRANS does not seek to use extensive real-time data but information derived from prior studies is adopted.

Table 5 presents an overview of some scenarios that have been employed when testing TRANS. These relate to road, rail and inland waterway transportation carrying as reference products, pentane, propane, acrylonitrile, and ammonia.[2]

Table 5 Scenarios, reference products and follow-up incidents per transport mode

Transport mode	Type of product	Scenario	Follow-up incident	Reference product
Road transport	Inflammable liquid	Rupture	Pool fire	Pentane
Railway transport		Rupture		
Inland waterway		Major leak		
Road transport	Toxic liquid	Rupture	Toxic vaporized liquid	Acrylonitrile

[2] In addition, and in cooperation with fire brigades, action maps are also drawn for Flanders that cover the most important products being transported via pipeline. On these maps effect distances are shown relative to a pipeline's diameter.

Transport mode	Type of product	Scenario	Follow-up incident	Reference product
Railway transport		Rupture		
Inland waterway		Major leak		
Road transport	Toxic gas	Rupture	Toxic vapour cloud	Ammonia
Railway transport		Rupture		
Inland waterway		Major leak		
Road transport Railway transport	Inflammable (liquefied) gas	Rupture	BLEVE (with fireball)	Propane
Inland waterway		Major leak	Vapour cloud explosion	Propane

Once the effect distance is determined, the potentially exposed population in found. If no exact data are available, generic data from the Dutch *Green Book* (VROM, 2005) are used to assessing this population. For more vulnerable locations (schools, hospitals, homes for elderly and day-care homes), generic data from the *Green Book* are used as well. There are also locations visited by the general public where populations congregate for such things as recreational activities, sports events, and concerts.

For each segment, the number of exposed people per segment length is normalized to individuals per kilometre. The surface area in the affected zone is multiplied by generic data from the *Green Book* to obtain the number of people per surface and per kilometre. In this recalculation people associated with vulnerable locations and at locations often visited in large numbers by the general public, are not taken into account to avoid population point locations being spread over large distances. This procedure produces consequence grades (Table 6).

Table 6 Relationship between persons per km and consequence grade

Consequence grade assessment	
CG 1	0 – 100/km
CG 2	101 – 250/km
CG 3	251 – 500/km
CG 4	501 – 1000/km
CG 5	1001 – 2000/km
CG 6	2001 – 4000/km
CG 7	4001 – 7500/km
CG 8	7501 – 12500/km
CG 9	12501 – 20000/km
CG 10	>20001/km

If in a segment a vulnerable location or one visited by the general public would be present, the consequence grade will be upgraded with one unit. To illustrate, if 548 pers/km are present in the effect zone of a segment and there are one or more vulnerable locations present in the segment, the segment is assessed to be *CG 5*. Without the presence of vulnerable locations the segment would be categorized as *CG 4*.

Route segment risk profile and transport route risk score

To obtain a risk profile of a route segment, four segment substance-related scores are needed. TRANS estimates these by multiplying for each hazardous substance category the *CG*-value with the *LG*-value and the resultant scores added. This gives an indication of the value of the complete segment. The risk contributions of each dangerous goods category per segment are also easy to compute.

A final step is to evaluate the risk along a transport route. On the premise that Guassian estimations are relevant, this involves combining the risks of the individual route segments. One way of doing this is to sum the route segment scores and divide by the number of segments; i.e.,

$$\text{Transport route risk score} = \frac{\sum_{j=1}^{j=n}\left(\sum_{i=1}^{i=4} CG_i \times LG_i\right)}{n}$$

where: i is the substance category; j is the route segment; n is the number of route segments associated with the transport route; LG_i is the likelihood grade for substance category i; and CG_i is the consequence grade for substance category i.

4. Conclusions

There is an increasing amount of hazardous material being moved that, in the event of an accident of some form of attack, could lead to serious environmental problems. The TRANS method described here is a semi-quantitative approach developed to determine risk levels associated with the transport of dangerous goods in Flanders, Belgium. It is seen is a first step and, for example, there is still a need to investigate the ways route length can influence risk and whether a short route with a high risk has the same implications for public safety as a long route with a low risk.

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